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EDITORIAL

TRIA-Net: 10 years of collaborative research on turning risk into action for the mountain pine beetle epidemic[1]

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Abstract: Forest insects are showing increasing intensity of outbreaks and expanded ranges, and this has become a major challenge for forest managers. An understanding of these systems often depends upon detailed examination of complex interactions involving multiple organisms. In 2013, a team of researchers formed TRIA-Net, an NSERC support Strategic Network, with the explicit goal of exploring such interactions in the mountain pine beetle (MPB; *Dendroctonus ponderosae* Hopkins, 1902) – pine (*Pinus* sp.) – blue stain fungi (Ophiostomatales) system. Contributions of this network include novel genetic and genomic resources and insights, as well as exploration of how landscape structure affects MPB movements. This review highlights the unique contributions of TRIA-Net to our understanding of the MPB outbreak system. We also highlight how the insights we generated can be used to inform management strategies — including assessing stand susceptibility, predicting spread, and developing better monitoring approaches — and how the approach taken by the TRIA project can be used as a model for tackling other challenging forest insect outbreaks.

Résumé : Les insectes forestiers montrent des infestations de plus en plus intenses et un élargissement des aires de répartition, ce qui est devenu un défi majeur pour les gestionnaires forestiers. Souvent, la compréhension de ces systèmes dépend d'un examen détaillé des interactions complexes auxquelles participent de multiples organismes. En 2013, une équipe de chercheurs ont formé TRIA-Net, un réseau stratégique de soutien du CRSNG, dans le but explicite d'étudier de telles interactions dans le système dendroctone du pin ponderosa (DPP; *Dendroctonus ponderosae* Hopkins, 1902) – pin (*Pinus* sp.) – champignons de bleuissement (Ophiostomatales). L'apport de ce réseau comprend de nouvelles ressources et connaissances en génétique et génomique, de même que l'exploration de l'influence de la structure du paysage sur les déplacements du DPP. Cette synthèse met en évidence les contributions uniques de TRIA-Net à notre compréhension du système d'infestation du DPP. Elle souligne également la façon dont les connaissances acquises peuvent être utilisées pour orienter les stratégies de gestion — notamment l'évaluation de la vulnérabilité des peuplements, la prévision des propagations et l'élaboration de meilleures méthodes de surveillance — et la façon dont l'approche adoptée par le projet TRIA peut servir de modèle pour lutter contre d'autres infestations d'insectes forestiers complexes. [Traduit par la Rédaction]

Since approximately 1999, an outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopkins, 1902 (Coleoptera: Scolytidae)) in western Canada has challenged governments, land managers, forestry-dependent communities, and researchers to find a way to stop its spread. Long-standing questions regarding the spatial drivers of irruptive population dynamics in forest insect pests rose once again to prominence as local, provincial, and federal governments grappled with the rapidly rising tide of red trees across the landscape. Millions of dollars were spent on direct management action such as containment and sanitation logging and on research in an effort to develop approaches to protect forest resources and to ensure ecosystem functioning and services provisioning. Although historical outbreaks of the mountain pine beetle are well known and have been well documented, this outbreak is considered to have been different. The acknowledged role of historical forest management and fire suppression, in combination with climate warming, in driving this unprecedented outbreak (Raffa et al. 2008) highlights the importance of considering such cumulative effects in other outbreak-prone systems.

Over 25 million hectares of forest have been affected by the mountain pine beetle in western North America since the outbreak was first detected in British Columbia 20 years ago (Bentz et al. 2010). The majority of trees affected were lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson), the mountain pine beetle's primary host. The consequences of this outbreak to the economy of British Columbia alone are estimated to be upwards of Can$90 billion (Corbett et al. 2016). In Canada, the outbreak continues to expand northward into the Northwest Territories and eastward through Alberta towards Saskatchewan. As beetle populations have been shown to successfully attack a novel host, jack pine (*Pinus banksiana* Lamb.) in Alberta (Cullingham et al. 2011), this outbreak, and potential future outbreaks, now pose a national-scale threat to the boreal forest and pines extending to the Great Lakes and even the East Coast.

While the mountain pine beetle outbreak has subsided in British Columbia in recent years, it continues to affect some parts of the province, particularly in the south and central-east near the Alberta border. In Alberta, the 2018 spring forecast survey pre-

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[1]This editorial introduces a series of papers developed through the NSERC-supported Strategic Network Grant "TRIA-Net". TRIA-Net's goal was to apply modern genomic and genetic approaches to improve our understanding of mountain pine beetle outbreaks and to provide tools to forest managers to reduce outbreak risk.

dicted mainly static populations in the Banff, Hinton, Slave Lake, and Peace River areas but also some expanding populations in the Slave Lake, Peace River, and Edson areas. Some populations (e.g., near Whitecourt) were predicted to decline. Whether declining, static, or growing, the presence of mountain pine beetle in most of those areas (except Banff) represents a dramatic range expansion across a vast area and into new jack pine hosts. While populations in the Lac La Biche forest area were predicted to decline, those populations are very near to the Saskatchewan border. There remains very real concern that the mountain pine beetle could continue its march eastwards with devastating consequences for Canada's pine forests. Most important is that after 20 years, this outbreak shows no sign of fully abating.

In 2013, in this context of mounting concern over the mountain pine beetle outbreak, the risk of eastward expansion into the boreal forest, and the potential damage to forest-dependent communities, a collaborative, multidisciplinary, and multi-institutional network was assembled. This network included investigators from the University of Alberta, the University of British Columbia, the University of Northern British Columbia, the Université de Montréal, the Canadian Forest Service, and representatives of the provinces of British Columbia, Alberta, and Saskatchewan, as well as highly engaged industry partners. Building on several years of support through Genome Canada, Genome Alberta, and Genome BC, this network collaboration took the form of an NSERC-supported Strategic Network grant: TRIA-Net.

The focus of the network included fundamental research on the ecology, population genetics, functional genomics, landscape dynamics, economic consequences, and other social impacts of the mountain pine beetle outbreaks. Our collective goal was to further develop the body of knowledge around mountain pine beetle outbreaks to better inform predictive modelling of outbreak spread in the context of climate change to inform forest management and policy. The consortium was designed to function as an interconnected series of multidisciplinary research areas that would collectively provide new insights into the outbreak from many different perspectives.

The name of TRIA-Net was selected to reflect the previous iterations of our research collaboration that began in 2008 and were funded by Genome Canada, Genome BC, and Genome Alberta. This original project was called TRIA, in reference to the three organismal groups that comprise the outbreak system: beetles, host pines, and symbiotic fungi. Once the NSERC Strategic Network was funded, we modified the name to TRIA-Net, which stood for "turning risk into action" for the mountain pine beetle epidemic, with additional emphasis on our network-based approach.

Over the 10 years of research on this system, we have made major advances in our understanding of the mountain pine beetle system. Through our novel collaborative approach involving a team with expertise ranging from entomology to functional genomics to landscape ecology, we successfully developed an enormous amount of new knowledge that has begun to have a real impact on how the outbreak is managed in both its historical and expanding ranges. Our collaboration provides a model for the development of similar groups working on complex, multispecies systems. This virtual special issue of the *Canadian Journal of Forest Research* highlights a subset of this work and points to additional studies undertaken under the banner of, or partially inspired by, this long-standing collaboration on the mountain pine beetle.

This special issue is comprised of eight articles that capture the depth and breadth of research on the mountain pine beetle outbreak system that was undertaken through TRIA-Net. Topics range from optimizing beetle surveillance strategies, to landscape and population genetic analyses, to social network analysis of human players in the outbreak.

Within a theme of improving management and our capacity to respond to outbreaks, Kunegel-Lion et al. (2019) present novel, cost-effective beetle monitoring and detection techniques that are much needed to inform effective control strategies. Gonzalès and Parrott (2019) applied a novel network theory approach to better understand how information flows through the human communities involved in and affected by mountain pine beetle outbreaks. They highlight the need for greater communication among stakeholders for improved management and responses to outbreaks of forest insect pests. These two contributions should help to manage future outbreaks and can be applied to other outbreaking pest systems.

Movement plays a key role in the spatial dynamics of mountain pine beetle outbreaks. Jones et al. (2019) present a thorough review of the main factors determining bark beetle flight and dispersal capacity, a poorly understood component of basic bark beetle biology. Their review provides a summary of the current state of knowledge and identifies key gaps in our understanding.

Much of our work focused on harnessing modern high-throughput sequencing technologies to examine the individual components of the outbreak system, as well as their interactions, through the lens of genetics. Tsui et al. (2019) describe genetic diversity in beetle-associated symbiotic fungi at a fine spatial scale. In describing these spatial genetic patterns, the authors illustrate the flexibility and potential adaptive capacity of the symbiont community to novel environmental conditions and explore how that flexibility might contribute to outbreak spread. Burns et al. (2019) provide a genetic-based predictive model to distinguish among lodgepole pine, jack pine, and their hybrids. This information is critical for ongoing monitoring and forecasting work to understand which stands and regions are more susceptible to mountain pine beetle attack. Wittische et al. (2019) used a landscape genetics approach to identify the environmental features that most affect mountain pine beetle dispersal. Their findings confirmed the importance of both elevation and climate but suggest few barriers to eastward migration into the future. Finally, Cullingham et al. (2019) provide a strong overview of the contributions of genetics and genomics to understanding mountain pine beetle outbreak dynamics. This contribution summarizes the large volume of work that has been carried out on mountain pine beetle genetics and genomics in the context of this long-running research program.

We hope that this special issue highlighting the many years of collaborative research within TRIA-Net will serve to guide ongoing collective efforts to manage and mitigate the mountain pine beetle outbreak. We also hope that the legacy of TRIA-Net as a highly productive interdisciplinary research network will serve as a template for other large-scale integrative projects. We thank the *Canadian Journal of Forest Research* for hosting a subset of the research from our network in this issue, and we look forward to continuing this work into the future.

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